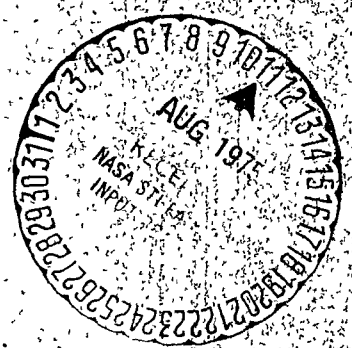
ABSTRACT

A technique is described for measuring the internal gas pressure of sealed secondary electrochemical cells. In use such cells are ordinarily restrained by a clamp or restraining device. The internal gas pressure can be determined by using a load cell to measure the force exerted by the secondary cell on this clamp.



(NASA-TM-X-74410) A NEW TECHNIQUE FOR MEASURING THE INTERNAL PRESSURE OF SEALED ELECTROCHEMICAL CELLS (NASA) 11 p

N77-74193

Unclas
00/98 30050

FACILITY FORM 602

X67-36107
(ACCESSION NUMBER)

11
(PAGES)

NASA-TM-X-59617
(NASA CR OR TMX OR AD NUMBER)

(THRU)
2A
(CODE)
03
(CATEGORY)

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A NEW TECHNIQUE FOR MEASURING THE INTERNAL PRESSURE OF SEALED ELECTROCHEMICAL CELLS

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INTRODUCTION

Secondary electrochemical cells to be used in aerospace applications are usually subjected to numerous characterization and acceptance tests. Because the battery is such a critical component in most space vehicles, this testing is usually very thorough and therefore includes virtually every externally measurable cell parameter.

It is therefore surprizing that one of the most important cell parameters, the internal cell pressure, is rarely ~~studied~~ (included in these acceptance tests). This anomalous situation is a consequence of the fact that cells which have been equipped with bourdon gauges or pressure transducers are more costly and unreliable. P. Bauer (1) has described an apparatus which makes it possible to measure the internal pressure of prismatic cells without such gauges or transducers. In its essence this

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apparatus consists of a pressure vessel which makes it possible to equalize the pressure within the cell and that of the oil in which it is immersed. Thus the cell pressure is determined by measuring the oil pressure. This approach to the problem is certainly ingenious and has been shown to have an accuracy which is more than adequate. Its disadvantages lie in the cost and complexity of the apparatus and in the time required for characterization of a large number of cells. These objections have precluded its adoption by the industry.

W. Scott (2) used a strain gauge to measure the flexure of the cell case due to internal pressure. He found, however, that because of hysteresis effects there is no simple relation between the strain and the internal pressure.

The method proposed here takes advantage of the fact that the broad faces of prismatic electrochemical cells must be supported by a clamp or restraining device. The force exerted by the cell walls on this clamp is obviously related to the gas pressure inside the cell. To estimate this internal gas pressure, one must measure the force and find the relation between the force and the pressure. The method described here is based on this approach.

The force is measured by means of an electrical transducer known as a "load cell". The type used in this investigation approximates a cube in shape and is designed to measure the force, compressive or tensile, that is exerted on two opposite faces of the cube. In use the load cell is interposed between the

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electrochemical cell and the clamp which restrains it. The expansive force exerted by the cell walls is borne by the load cell as a compressive stress and can be measured electrically.

Experimental Approach

To establish the relation between this force and the gas pressure inside the cell, one proceeds as follows: It is first necessary to obtain an electrochemical cell that is equipped with a bourdon gauge or pressure transducer and with a tube which can be connected alternately to either a vacuum pump or a cylinder of compressed inert gas. It is important that this cell be essentially identical in all other respects to the flight cells to be tested.

This specially equipped "calibrating cell" is clamped against a load cell in an assembly like that shown in Figure 1. The cell is then evacuated (0-2 psia) and next, by turning the adjusting nut (Figure 1), the load cell output is adjusted to be equivalent to the normal clamping force for the electrochemical cell. In the case of a 6-ampere-hour nickel-cadmium cell, a force of about 100 pounds is satisfactory. (It will be shown below that this adjustment is not critical). The next step is to increase the gas pressure inside the calibrating cell to about 100 psia in increments of 5 to 10 psi. After each addition, readings are taken of both the load cell output and the calibration cell internal pressure as indicated by the gauge or transducer. When the desired maximum pressure has been reached,

this calibration process should be repeated as gas is removed incrementally. A comparison of the two sets of readings will reveal any hysteresis.

The data taken during such a calibration experiment are shown graphically in Figure 2. The purpose of this experiment is to obtain the slope of the line shown in this figure, i.e., the change in gas pressure per pound of change in the load cell output. The output at zero gas pressure is, of course, the initial clamping force.

The slope obtained by means of the calibration experiment just described is then used in measuring the pressure in "regular" cells, i.e., cells without bourdon gauges or pressure transducers. The cell in question is first clamped against the load cell as described above and the "zero pressure"* load cell output is noted. When it is desired to measure the cell's internal pressure, the load cell output is again noted; this second value of the output is decreased by the first and then multiplied by the known slope of the force-pressure curve obtained as a result of the calibration experiment. The result of this calculation is the desired pressure measurement.

*The term "zero pressure" refers to the pressure inside a cell that has not been in recent use. The actual value can ordinarily be obtained from the manufacturer.

EVALUATION OF ERRORS

Experience with this technique indicates that a careful experimenter can expect an error that does not exceed 10 percent of the pressure measured. The sources of error which are believed to be important are discussed below. All of the results were obtained using a single type of sealed 6-ampere-hour nickel-cadmium cell, all with drawn stainless steel cans and all from the same manufacturer.

1. Hysteresis

A typical calibration curve is shown in Figure 2. The encircled data points were obtained as the cell pressure was increased, and those enclosed by a square were taken while it was decreased. The amount of hysteresis shown here is typical of the cells studied: appreciable, but insignificant as compared with other sources of error.

2. Temperature

Figure 3 is indicative of the amount of error introduced by temperature variations. These curves were obtained by "calibrating" the same cell at the temperatures indicated: 10°, 25°, and 40°C. The total spread in pressure is seen to be about 10 psi with 50 psia in the cell. The source of uncertainty can be eliminated by generating calibration curves at each of the several temperatures at which pressure measurements are to be made.

3. Initial Clamping Pressure

The initial clamping force or "zero pressure load-cell reading" has a small effect on the slope of the calibration curve. This effect was evaluated by calibrating five cells, first with an initial clamping force of about 75 lb and then with about 150 lb. The average change in slope for the five cells was 0.012 psia/lb and the maximum change was 0.024 psia/lb. With 50 psia in the cell, this change would cause error of 2 psia and 4 psia respectively. In all five cases, the larger initial clamping force caused an increase in slope.

4. Cell-to-Cell Variations

The slope of the calibration curve does not depend solely on the gas pressure within the cell. It is to some extent dependent on the dimensions and metallurgical properties of the cell case and on the compressibility and resilience of the plate pack. This fact casts some doubt on the measuring technique advocated here since these cell properties could differ sufficiently to introduce serious errors, even among presumably identical cells.

This possibility has been explored by calibrating two groups of cells containing five cells each. The first group consisted of cells which had never been used and were therefore essentially identical. The calibration curves for this first group are given in Figure 4. To facilitate visual comparison of their slopes, these curves were translated in such a way as to cause all five curves

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to pass through the origin. The slopes were unchanged in the process.

Figure 5 gives the results obtained from the second group referred to above and is identical to Figure 4, except that the cells involved had very different (and in some cases unknown) histories. At least one was a leaker and had probably dried up. Note that in the first case (Figure 4) the total spread in the vicinity of 50 psia is only about 3 psia, which implies an error of about ±1.5 psia around an average or ±3 percent at any given pressure reading. In the second group, however, the spread in the vicinity of 50 psia is approximately 24 psia which corresponds to an error of ±12 psia or ±24 percent.

It is logical to assume that the large differences in slope seen in Figure 5 are a consequence of the markedly different histories of the cells involved. It follows that cells having essentially the same history would have similar calibration slopes even though those slopes might change as the cells age or wear out. Thus, it should be possible to evaluate this change and maintain accuracy by subjecting a group of calibration cells to the same use as that of the test cells.

In other words, the error caused by ageing, like that caused by temperature changes, can be minimized or eliminated if the experimental objective warrants the additional effort and expense.

Discussion and Recommendations

This paper describes a method whereby the internal pressure of sealed electrochemical cells can be measured. There are, however, several experimental parameters that could conceivably be important in the use of this method. These are discussed below.

1. Cell Size

All the experimental work described above is based on studies of a single type 6 ampere-hour cell. A few experiments made on a 4 ampere-hour cell tended to confirm these findings. However, data are needed on the larger cell sizes, e.g., 20 and 50 ampere-hours. This would make it possible to study the relations between the area of the cell face, the internal gas pressure, and the expansive force which results.

2. Pressure Pad Size

The broad faces of prismatic cells can be concave, convex, or essentially flat. If either face is concave, it is obvious that a clamping plate which completely covers this face will be supported solely by the cell edges and that the accuracy of the proposed measuring technique would be adversely affected. To avoid this problem, the measurements described in this paper were made with one steel pad interposed between the cell and the clamping device on one side

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and another between the cell and the load cell on the other (See Figure 1). These pads are 1/2 inch thick and have 1-1/8 by 2-1/2 inch bearing surfaces. Since each broad cell face is about 2-1/8 by 3-7/8 inches, the pad covered only a central rectangle of the cell face, leaving unsupported a peripheral margin about 1/2 inch wide. Also, to isolate the cell case electrically, a thin (1/32 inch) sheet of epoxy-glass-cloth laminate was interposed, on both sides, between the cell case and the steel pad.

It is possible that both the dimensions of the steel pads and the hardness of the plastic sheet affect the slope of the calibration curve. Neither of these factors has been investigated. It seems probable that errors from these sources can be avoided if calibrations and measurements are both made under the same experimental conditions. Also, it seems advisable to use a plastic insulator with a minimum tendency to creep.

3. Load Cell Type

The load cells used during this investigation are of a single type and size. Their operation depends on the piezo-resistive characteristics of a semi-conductor which forms one arm of a Wheatstone bridge. In many applications, this type of load cell has advantages over less expensive types which justify its use. However, the degree of accuracy required by the present application makes it probable that a less expensive load cell would be satisfactory. This should be investigated

4. Initial Clamping Force

In the course of this study, it was observed that the initial value of the clamping force or "zero pressure load-cell output" often changed significantly from its initial setting after the assembly had been allowed to stand for several hours. For best accuracy, it is therefore advisable to record this zero pressure force after the cell has been clamped overnight.

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2. Walter Scott, 1963 private communications.